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Towards achieving energy for sustainable development in Nigeria

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A B S T R A C T

The importance of energy availability in the economic growth, social and political development of every nation cannot be overemphasized. Affordable and reliable energy availability is the precondition for sustainable development. Sustainable development calls for an efficient, reliable and decentralized energy economy, based on local and clean energy sources, in which the price paid by the consumer will reflect the real cost of energy products to the economy. There is clear evidence that Nigeria is blessed with abundant resources of fossil fuels as well as renewable energy resources. The major challenge is inefficient utilization of energy in the country. There is no doubt that the present power crisis afflicting Nigeria will persist unless the government diversifies her energy sources and adopt new available technologies to reduce energy wastages and save cost. This study examines the perspective of energy efficiency and renewable energy in the making of strategies for a sustainable development in Nigeria. Such strategies involve energy savings on the demand side, efficiency improvements in the energy production, and replacement of fossil fuels by various sources of renewable energy. Factors that need to be considered in the shift to its sustainable energy future are examined in this article.

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1. Introduction

Energy is one of the most fundamental issues for sustainable development. Sustainable development is a changing process, circuiting investment, orientating technology and institution for compatible with the needs of the present and the future. Electricity is conceivably the most multipurpose energy carrier in modern global economy, and therefore primarily linked to human and economic development [1].

Globally, the quest for sustainable development has heightened today more than ever before. There are increasing awareness and concern for sustained economic development and growth.

Sustainable energy has turned into one of the most promising ways to handle the challenges of energy demand problems of numerous consumers worldwide [2].

Sustainable Energy Development Strategies typically involve three major technological changes: energy savings on the demand side, efficiency improvements in the energy production, and replacement of fossil fuels by various sources of renewable energy. Consequently, large-scale renewable energy implementation plans must include strategies for integrating renewable sources in coherent energy systems influenced by energy savings and efficiency measures [3].

The importance of energy in the economic, social and political development of every nation cannot be overemphasized. Transportation, industrial activities, communication, health, and education are some of the areas where energy cannot be substituted. Improvement in standard of living is manifested in rise in food production, increased industrial output, the provision of efficient transportation and telecommunication, adequate shelter, improved healthcare delivery and other human services; each of these requires increased energy consumption. Thus, future energy requirement is expected to grow with increase in standard of living, industrialization and other socio-economic factors. However, inadequate supply of energy restricts socio-economic activities, constrains economic growth and adversely affects the quality of life [4].

Energy is a critical input for the achievement of many of the Millennium Development Goals, including eradicating extreme poverty and hunger, achieving universal primary education, promoting gender equality and empowering women, reducing child mortality, improving maternal health, combating diseases, and ensuring environmental sustainability. For adults and children, gaining access to reliable electricity enhances their quality of life and enables income-generation. Modern cooking and heating solutions can transform the lives of billions—many of whom spend hours collecting and transporting firewood and other forms of biomass, and all of whom are exposed to household air pollution from solid fuels, which killed an estimated 3.5 million and caused many more cases of respiratory, cardiovascular, and other illnesses in 2010 [5]. Beyond household access, electricity is a critical input to the effective delivery of social services, which help lift populations out of poverty and enable economic growth. Lighting, refrigeration, and effective sterilization procedures enabled by electricity supply make healthcare far more effective, and electricity similarly improves education by enabling superior lighting and powering of computers and other equipment.

For Nigeria to meet up with the Vision 20:2020; Nigeria requires power generating capacity of 140,000 MW as against the current capacity of about 8039 MW [6]. This will put Nigeria slightly below South Africa with per capita power capacity of 1047 W, UK with per capita power capacity of 1266 W and above Brazil with per capita power capacity of 480 W, China with per capita power capacity of 260 W [7]. Currently Nigeria has per capita power capacity of 28.57 W and this is grossly inadequate even for domestic consumption. To the much desired millennium development goals a strong energy sector is essential for a vibrant and competitive economy.

The National energy supply is at present almost entirely dependent on fossil fuels and firewood (conventional energy sources) which are depleting fast. Despite the abundance of energy resources in Nigeria, the country is in short supply of electrical power. Access to reliable and stable supply of electricity is a major challenge for both the urban and rural dwellers. Only about 40% of the nation's over 140 million has access to grid electricity and at the rural level, where over 70% of the population live, the availability of electricity drops to 15% [8]. An analysis of Nigeria's electricity supply problems and prospects found that the electricity demand in Nigeria far outstrips the supply, which is epileptic in nature. The acute electricity supply hinders the country's development and not only restricts socio-economic activities to basic human needs; it adversely affects quality of life.

Nigeria's unreliability of supply and decline in traditional fossil fuel production, combined with very grave environmental matters and continued uncharted economic and population growth makes it imperative to search for alternative forms of energy. Whilst proceed with increasing the generation capacity, transmission and distribution of existing traditional energy sources through the development of energy systems and policies that enhance social, economic and environmental performance; it is appropriate to focus on alternative to the traditional energy sources which among other things is capital intensive, and the technology required becomes obsolete with a short space of time thereby requiring intensive overhauling of the machineries or better still a complete replacement of the existing technology with a newer innovation leading to colossal waste of fund. However, the answer to the present imbroglio may be found in renewable and sustainable energy forms both for rural and urban areas of the country.

Researches have shown that Nigeria is endowed with abundant energy resources which have not been properly managed to satisfy the nation's energy needs [2,4,8–10]. Government's over-dependency, and excessive fixation, on oil has slowed down the development of alternative sources of energy, even when the need is glaring. In a bid to attract and encourage investment in renewable energy in Nigeria, the government needs to put in place the necessary mechanisms that will aid renewable energy development and production in Nigeria. One of the challenges of this effort is the absence of a legal framework to regulate the industry. Clear rules, legislation, roles and responsibilities of various stakeholders along every stage of the energy flow from supply to end-use are key elements of the overall policy framework needed to promote renewable energy technologies. Such policy, legal and institutional frameworks are at their beginning stage in Nigeria and are being developed under the reform programme.

Effective policy and regulatory frameworks for advancing renewable energy in Nigeria are paramount to: (i) achieve long term reductions in carbon emissions; (ii) enhance the energy security of the country and establish a sustainable energy supply system; (iii) promote the policy of diversifying the energy supply so as to include renewable resources and technologies into the nation's energy supply mix and (iv) make electricity accessible to the rural dwellers through grid extension and mini-grids, considering that the level of electrification in the country is very low.

The aim of this paper is to: (i) identify the exploitable energy resources in Nigeria (ii) review pattern of energy consumption in Nigeria (iii) identify strategies of delivering access to modern energy and (iv) ascertain the effect of utilizing renewable energy resources and efficient energy as possible means of sustainable development in Nigeria.

2. Energy and development in Nigeria

2.1. Conventional energy resources

In its mix of conventional energy reserves, Nigeria is simply unmatched by any other country on the African continent. It is not surprising; therefore, that energy export is the mainstay of the Nigerian economy. Also, primary energy resources dominate the nation's industrial raw materials endowment [11].

Nigeria is richly endowed with a lot of the conventional energy resources which include petroleum, gas, coal and hydro. These resources are distributed in the various parts of the country. Coal deposits are found in large commercial quantities in places like Enugu and Okaba mines in Enugu and Kogi states respectively. Petroleum and its associated gas are found in commercial quantities in the southern part of the country, in places like Rivers, Bayelsa, Imo, Abia, and Delta states. Rivers suitable for hydropower are located in places like Kainji, Shiroro, Jebba, Makurdi, Mambilla, Lokoja etc.

Several energy resources are available in Nigeria in abundant proportions. The country possesses the world's sixth largest reserve of crude oil. It is increasingly an important gas province with proven reserves nearly 5000 billion cubit meters. Coal and lignite reserves are estimated to be 2.7 billion tons while tar sand reserves represent 31 billion barrels of oil equivalent. Identified hydroelectricity sites have an estimated capacity of about 11,250 MW [12]. Nigeria has significant biomass resources to meet both traditional and modern energy uses, including electricity generation [13]. Table 1 shows Nigeria's energy resources. There has been a supply–demand gap, as a result of the inadequate development and inefficient management of the energy sector. The supply of electricity, the most utilized energy resource in the country has been erratic [8].

Nigerian economy depends heavily on oil which accounts for more than 95% of export income and also accounts for almost 85% of the nation revenues. Nigeria has an estimation of 36. 2 billion barrels of oil reserves as of 2009, it is 10th largest country in the world that produces oil. In addition to oil, Nigeria had proven gas reserves of more than 5000 billion cubic meters; it is the 7th largest gas reserve country in the world [14].

2.2. Energy consumption pattern in Nigeria

The energy use patterns in Nigerian economy can be divided into industrial, transport, commercial, agriculture and household sectors [16]. The household sector accounts for the largest share of energy use in the country – about 65%. This is largely due to the low level of development in all the other sectors.

The forms of energy consumed in Nigeria have increasingly diversified with innovations in science and technology. In the earliest times, like everywhere else in the primitive world, energy was consumed in the primary renewable form, essentially as biomass in the form of wood fuel and solar energy. Later, at the turn of the present century, primary non-renewable energy forms were introduced from fossil fuels. Only coal was used initially, but later, petroleum products and natural gas were included. These primary forms, which were used mainly for transportation, dominated the energy scene for several years until the principal secondary form, electricity, was introduced.

The production and consumption of various forms of energy in Nigeria from pre-colonial till date (before 1960 till date) are discussed below.

2.2.1. Coal production and consumption

Coal was the first fossil fuel to be discovered and used in Nigeria. Oil was discovered about 47 years after discovery of coal [17]. Coal production in Nigeria started in 1916 with an output of 24,500 t for that year. Production rose to a peak of 905,000 t in the 1958/59 year with a contribution of over 70% to commercial quantities in 1958 and the conversion of railway engines from coal to diesel, production of coal fell from the beginning of the 1960s of only 52,700 t in 1983 [18].

Table 1
Conventional energy resources in Nigeria.
Sources: Ref. [15].

S/N	Resource type	Reserves		Production	Domestic utilization
		Natural units	Energy units (Btoe)		
1.	Crude Oil	36 billion barrels	4.76	2.5 million barrels/day	445,000 barrels/day
2.	Natural gas	187 trillion SCF	4.32	7.1 billion SCF/day	3.4 billion SCF/day
3.	Coal and Lignite	2.734 billion tonnes	1.92	Insignificant	Insignificant
4.	Tar Sands	31 billion barrels of equivalent	4.22	–	–
5.	Large Hydropower	11,250 MW	1.11 (over 38yrs)	1938 MW (167.4 million MWh/day)	167.4 million MWh/day

During the civil war years of 1967–1969, production stood at only 20,400–35,000 t. This rose to 323,000 t in 1972 and progressively declined to 118,000 t in 1980. The estimated cumulative production between 1916 and 1980 is about 25.3 million metric tonnes. In 1980 coal contributed less than 1% to commercial energy consumption in the country as compared to 70% for oil, 25% for natural gas and about 5% for electricity.

Over 95% of the Nigerian coal production has been consumed locally, chiefly for railway transportation, electricity production, and industrial heating in cement production lines. Between 1952 and 1958, coal consumption by the Nigerian Railway Corporation accounted for about 60% of the overall consumption. Due to its diesel conversion programme, commenced in 1966, its share of coal consumption fell progressively to $<30\%$ in 1966, and to an insignificant level in 1986. The other major consumer, the National Electric Power Authority (NEPA) (now the Power Holding Company of Nigeria Plc, PHCN), had about a 16–30% share of the total consumption between 1952 and 1966. As a result of the civil war, its sole coal fired electricity generating station was put into disuse. Consequently, its coal consumption has been insignificant since 1970. The cumulative effect of the decline in demand by the two major consumers, together with the ease and cost-effectiveness associated with the use of other energy sources, resulted in the edging out of coal in the national energy scheme [19].

2.2.2. Petroleum production and consumption

Petroleum exploration in Nigeria witnessed steady growth over the past few years. Proven recoverable reserves of crude oil amount to about 1.48×10^6 billion tonnes, with commercial production commencing in 1958. The production then was only 3.1 million metric tonnes, but rapidly increasing market demand forced this to rise to 20.3 million tonnes in 1960, 54.2 million tonnes in 1970, and 104.1 million tonnes in 1980. The observed increases in production have been determined by external market forces, rather than increased local demand. The later rose from only 1.3 million tonnes in 1970 to barely 6.5 million tonnes/year in 1980. The average domestic consumption to the total production standing at an average value of 3% within the period. Thus, some 97% of the total production is exported, usually as crude oil. The local consumption of petroleum products is supplied from three refineries with a total combined capacity of about 13.5 million tonnes/year since 1980. Supply for the petroleum products up till 1980 was supplemented by imports, while 30% of the output of residual oil was exported. Based on various oil prospects already identified especially in the deepwater terrain and the current development efforts, it is projected that proven reserves will reach about 40 billion barrels by year 2020 and potentially 68 billion barrels by year 2030. Oil production in the country also increased steadily over the years; however, the rate of increase is dependent on economic and geopolitics in both producing and consuming countries. Nigeria's current production capacity is about 2.4 million barrels per day even though actual production is averaging around 2.4 million barrels per day partly due to the problems in the Niger Delta and OPEC production restriction. Average daily production is projected to increase to 4.0 million barrels per day by 2010 and potentially to over 5.0 million per day in year 2030 [20]. The consumption of petroleum products stood between 80% and 90% of the total commercial energy consumption over the 13 years from 1971 to 1984. The growth rate over the period averaged about 18%, with gasoline 22%, kerosene 17% and diesel 16%. Gasoline and gas oils are mainly used for transport (77%), household uses (12%) and industrial/commercia1 operations (11%). Half of the household consumption was used for operating standby electricity generators.

The present dependence on fossil fuel (petroleum) is not enough to meet the energy needs of the country. Interest in renewable energy development and dissemination in Nigeria is driven by, among others, the recent increase in oil prices, unavailability of electricity to majority of the population as well as high cost and energy losses associated with grid extension. The government had made effort through her several power reform programmes and policies to attract private participation, thus encourage RE development. However, there are hindrances, mainly due to the technical and financial barriers, that need to be overcome for this to be a reality [11].

2.2.3. Production and consumption of natural gas

The Nigerian reserves of natural gas are estimated at 4.67×10^{12} m^3 at a mean specific volume of 1.56×10^{-3} m^3/kg, a mean gauge pressure of about 12 bar and a calorific value of 35 MJ/m^3. The current production rate stands at about 1.8×10^{10} m^3/year, usually as associated gas [16]. About 8.5 m^3 of gas can be expected per barrel of crude petroleum. Since the infrastructure for gas utilization is underdeveloped in Nigeria, as high as 75% of the gas produced was being flared in the past. However, gas flaring was reduced to about 36% as a result of strident efforts by the Government to monetize natural gas. Domestic utilization of Natural gas is mainly for power generation which accounted for over 80% while the remaining are in the industrial sector and very negligible in the household sector. Given the current reserves and rate of exploitation, the expected life-span of Nigerian crude oil is about 44 years, based on about 2 mb/day production, while that for natural gas is about 88 years, based on the 2005 production rate of 5.84 bscf/day [21]. It is therefore, strategically important to undertake major investments in the gas sector in order to prepare adequately for gas as a substitute for oil both for domestic needs and foreign exchange earnings.

In 1988, the Nigerian Gas Company (NGC) was created as a subsidiary and strategic business unit of the Nigerian National Petroleum Corporation (NNPC). NGC is responsible for the development of policies governing transmission, distribution, marketing, utilization, as well as pricing of Nigeria's natural gas and its derivatives to a domestic market and neighbouring countries along the West African Coast [22]. The NGC has a monopoly on natural gas transmission and its facilities consist of eight supply systems that supply gas for its primary markets that include government-owned utilities companies for power generation and large-scale industries across the country. NGC receives its natural gas supplies from the major International Oil Companies (IOCs) producers operating in Nigeria such as Shell, Chevron, ENI/Agip and ExxonMobil [23].

In view of the increasing domestic oil consumption, an economically optimal strategy to replace oil with gas and gas derivatives will enhance the availability of more oil for export. This will also promote the conservation of the oil reserves. Apart from the economic advantage, fuel substitution from oil to gas is more environmentally friendly because gas is a cleaner fuel than oil.

As part of efforts aimed at restructuring the domestic gas sector and improve domestic gas availability and reliability, the Government approved the Gas Master Plan, Gas Infrastructure Blueprint and the Domestic Gas Supply Obligation. These policies aim to improve the long-term development of the gas sector and address the price distortions in the domestic gas sector. Gas resources can only be developed when the gas can be economically produced and transported to markets. Consequently the price of natural gas should vary considerably from region to region, determined by local costs of production and transportation distance [24].

Table 2
Commercial primary energy consumption by type.
Source: Ref. [25].

Type	Average % of total						
	2002	2003	2004	2005	2006	2007	Average
Coal	0.03	0.03	0.03	0.03	0.05	0.05	0.037 (insignificant)
Hydro	11.93	14.20	17.39	12.04	17.03	23.90	16.08
Natural gas	2.84	1.9	4.54	5.5	7.52	8.73	5.17
Petroleum Products	85.20	83.87	78.04	82.45	75.44	67.32	78.72

Table 3
Changes in fuel petroleum products consumption (2003–2007).
Source: Ref. [26].

Fuel product	Changes in consumption levels (%)				
	2003	2004	2005	2006	2007
Liquified petroleum gas (LPG)	−6.4	30.5	0.3	−8.1	−0.26
Premium motor spirit	0.44	11	0	−0.19	−2.96
Dual purpose kerosene (DPK)	−28.3	−19.2	0	−25.8	−52.4
Low pour fuel oil (LPFO)	20	10.8	0	−42.5	−42.8

The existing gas distribution pipeline infrastructure is inadequate in capacity and accessibility for the projected demand growth. The lack of connectivity between the existing gas supply systems limits the flexibility of supply in Nigeria.

Tables 2 and 3 show commercial primary energy consumption by type in percentage from 2002 to 2007 and changes in fuel petroleum products consumption from 2003 to 2007 respectively. It should be noted from Table 2 that while coal has over a long period been neglected, petroleum has constituted over 80% of the commercial primary energy consumed in the country. Despite the fact that petroleum products constituted the highest energy resources consumed in the country, however, Table 3 shows that its consumption has been falling over the years. This is as a result of depletion nature of the fossil fuel (petroleum). This calls for urgent attention of evolvement of renewable energy resources in energy sector so as to preserve crude oil in Nigeria.

2.2.4. Production and consumption of wood fuel

Wood fuel contributed about 5% of the fuel consumption of the Electricity Corporation of Nigeria (Now Power Holding Company Nigeria (PHCN)) in 1952/1953, but this decreased gradually to zero by 1960 [27]. Small quantities were also used for rail transport during the same period. The most significant use of fuel wood, however, is for domestic cooking and baking and heating in small-scale industries such as bakeries and brickworks. Presently, the largest sources of fuel wood are communal bushes and private farmlands, from whence fire wood is fetched freely or at a small fee. Between 1961 and 1973, the fuel wood consumption increased by 37% from 41.5 million m^3 in round wood equivalent to 56.8 million m^3. The 1973 consumption amounted to about 9.1×10^{11} MJ, or an equivalent of 12.1 million tonnes of oil. The projected consumption for 1985 and 2000 are, respectively, 17.8 and 23.6 million tonnes of oil equivalent.

3. Electricity generation and consumption

Electric power is a critical infrastructure for sustainable economic growth and development. This is because most economic activities are dependent on affordable and adequate energy for effective operation. It is critical for reducing the cost of doing business, enhancing productivity and quality of life [28].

Table 4
Electricity generation and utilization in Nigeria from 1980 to 2009.
Source: Refs. [38,39].

Year	Installed capacity (MW)	Generation capacity (MW)	Capacity utilized(%)
1980	2507	783.9	31.3
1981	2755	895.0	32.5
1982	2872	929.2	32.4
1983	3192	945.5	29.6
1984	3572	978.7	27.4
1985	4192	1133.4	27.0
1986	4574	1300.9	28.4
1987	4574	1227.5	26.8
1988	4574	1273.4	27.8
1989	4960	1398.5	28.2
1990	4548	1536.9	33.8
1991	4548	1647.2	36.2
1992	4548	1693.4	37.2
1993	4548.6	1655.8	36.4
1994	4548.6	1772.9	39.0
1995	4548.6	1810.1	39.8
1996	4548.6	1854.2	40.8
1997	4548.6	1839.8	40.4
1998	4548.6	1724.9	37.9
1999	5580	1859.8	33.3
2000	5580	1738.3	31.2
2001	6180	1689.9	27.3
2002	6180	2237.3	36.2
2003	6130	2378.4	38.8
2004	6130	2763.6	45.1
2005	6538.3	2494.4	38.2
2006	5898	2523.9	42.8
2007	5898	2623.1	44.5
2008	8351.4	4076.2	48.8
2009	8702.25	4035.5	46.4

The inadequate provision of power has a pervasive impact on socio-economic activities and consequently the living standard of citizens in Nigeria. Most of the nation's infrastructure in the power sector was built in the 1960s, 1970s and 1980s. Due to lack of maintenance and expansion of the facilities, the country has suffered significantly from the impact of epileptic and limited availability of electricity supply. In spite of the abundant energy resources in the country and the huge Government investments in the sector over the last 10 years, electricity supply remains a serious challenge to Nigeria's socio-economic development [29].

Electricity production in Nigeria over the last 40 years varied from gas-fired, oil-fired, hydroelectric power stations to coal-fired with hydroelectric power system and gas-fired system taking precedence. This is predicated by the fact that the primary fuel sources (coal, oil, water, gas) for these power stations are readily available [30].

Historically, electricity generation in Nigeria dates back to 1896 when two small generating sets were installed to serve the then Colony of Lagos, 15 years after its introduction in England [31,32]. By 1961, the total installed capacity was about 185 MW, which increased to 805 MW by 1970 and 2800 MW by 1983 [33].

The historical installed capacity, generation capacity and capacity utilization in Nigeria over the period of 1980–2009 are presented in Table 4. A close look at the table shows that the Nigeria's electricity industry is operating far below its installed capacity and the optimal level of production. This reflects the extent of inefficiency in the sector.

Total generation capacity over the period of 1980–2009 ranged from 783.9 to 4076.2 MW, while the installed capacity ranged from 2507 to 8702.25 MW [34]. There is a wide gap between generation capacity and installed capacity. For over two decades (1980s–2000s), the generation capacity by PHCN was less than half installed capacity.

The fluctuation of capacity utilization at different times in Table 4 is due to huge energy losses as a result of poor power plant maintenance, fluctuations in water levels powering the hydro plants, resistive and other losses (e.g. unmetered consumption, theft, etc.) in transmission grid and distribution lines, and more importantly, lack of spinning reserve inbuilt in PHCN power short and long term plans. The above reasons among others account for the increasing gap between demand and supply of electricity in addition to about 30–47% losses of electricity generated in transmission due to old transmission infrastructure of the Power Holding Company of Nigeria (PHCN) [35].

Despite the importance of infrastructural services to economic development, the consumption of electricity in Nigeria has been very low due to inadequate supply. This possibly might have been responsible for the slow rate of development in the country. Electricity consumption in the country stood at just 137 kWh per head in 2007 [36]. At 137 kWh per capita, electricity consumption is one of the lowest in the world.

A most regrettable situation is that electricity sector has never contributed up to 2% of the economic value added and 1% of the economic development (growth) of Nigeria. Currently, Nigeria's electricity sector contributes only 0.32% and 0.22% to economic value added and economic growth respectively. This possibly reflects the poor state of infrastructural developments in the country and the reason why Nigeria is ranked among the top poor economies in the world despite its abundant natural endowment [37].

Notwithstanding the above pitfalls that had rendered public electricity supply in Nigeria unreliable and inefficient, the trend of its utilization has grown significantly over the past years. The consumption of electricity in Nigeria has centred around three major sectors namely, industrial, residential, and commercial and public services. From Table 5, the proportion of electricity used for industrial purposes has decreased significantly while residential consumption has risen substantially. Industrial electricity consumption declined from 62.9% to just 9.7% in 2005 and currently stands at 20%. Similarly, residential consumption rose from 37.1% to 63.8% between 1970 and 2005 and currently accounts for 55.3% of total electricity consumption in the country. This low industrial consumption is easily explained by the intermittent power supply that has forced many small industries out of operation and many of the big industries to rely heavily on their privately owned diesel generator using less power from the national grid [4,40].

Table 5
Electricity consumption pattern in Nigeria in MW per hour.
Source: Refs. [42,43].

Year	Total	Industrial	% of Total	Residential	% of Total	Commercial & public services	% of Total
1970	145.3	91.4	62.9	53.9	37.1	NA	NA
1971	181.1	114.9	63.5	66.2	36.5	NA	NA
1972	211.1	138.2	65.5	72.9	34.5	NA	NA
1973	232.7	146.1	62.8	86.6	37.2	NA	NA
1974	266.2	163.2	61.3	103	38.7	NA	NA
1975	318.7	200.4	62.9	118.3	37.1	NA	NA
1976	369.8	214.6	58	155.2	42	NA	NA
1977	435.7	253	58.1	182.7	41.9	NA	NA
1978	504.4	157.7	31.3	253.2	50.2	93.5	18.5
1979	460.1	160.3	34.8	221.9	48.2	77.9	16.9
1980	536.9	199.7	37.2	243.1	45.3	94.1	17.5
1981	335.9	121	36.0	193.6	57.6	21.3	6.4
1982	685.6	262	38.4	344.5	50.6	79.1	11.6
1983	696.7	254.4	36.5	358	51.4	84.3	12.1
1984	625.5	217.2	34.7	326.6	52.2	81.7	13.1
1985	717.4	259.8	36.2	372	51.9	85.6	11.9
1986	841.8	280.5	33.3	476.6	56.6	84.7	10.1
1987	852.9	294.1	34.5	468.6	54.9	90.2	10.6
1988	853.5	291.1	34.1	443.8	52	118.6	13.9
1989	976.8	257.9	26.4	523.6	53.6	195.3	20
1990	888.5	230.1	25.6	450.8	50.3	217.6	24.3
1991	946.6	253.7	26.8	459.3	48.5	254.1	26.8
1992	993	245.3	24.7	481.6	48.5	266.1	26.8
1993	1141.4	237.4	20.8	592.4	51.9	311.6	27.3
1994	1115	233.3	21.3	575	52.5	306.7	28
1995	1050.9	218.7	20.3	552.6	51.3	279.6	26
1996	1033.3	235.3	22.8	518	50.1	280	27.1
1997	1009.6	236.8	23.5	508.3	50.3	264.5	26.2
1998	972.8	218.9	22.5	500	51.4	253.9	26.1
1999	883.7	191.8	21.7	455.1	51.5	236.8	26.8
2000	1017.3	223.8	22	518.8	51	274.7	27
2001	1104.7	241.9	21.9	564.5	51.1	298.3	27
2002	1271.6	146.2	11.5	752.8	59.2	372.6	29.3
2003	1519.5	196	12.9	905.6	59.6	417.9	27.5
2004	1825.8	398	21.8	938.5	51.4	489.3	26.8
2005	1873.1	182.3	9.7	1194.3	63.8	496.6	26.5
2006	1742.94	383.45	22.0	894.07	51.3	465.41	26.7
2007	2245.57	494.07	22.0	1151.95	51.3	599.55	26.7
2008	2113.83	422.72	20.0	1168.96	55.3	522.15	24.7

Thus, many companies had resolved in providing their own power generating sets as sources of electricity leading to a huge transfer costs on their products and services. MTN – the South African mobile phone company and the largest mobile phone supplier in Nigeria – is estimated to have installed 6000 generators to supply its base stations for up to 19 h/day. The company spends $5.5 million on diesel fuel to run the generators [41]. Similarly, the rise in domestic consumption can be ascribed to significant population increase that has put upward pressure on residential demand over this period.

3.1. Access to electricity and distribution system reliability

Household access to electricity services in Nigeria is low. About 60% of the population – over 80 million people are not served with electricity and rural and semi-urban access to electricity estimated to be about 35%. Per capita consumption of electricity is approximately 125 kWh against 4500 kWh, 1934 kWh and 1379 kWh in South Africa, Brazil and China respectively [44]. Table 6 shows the percentage distribution of households by source of electricity consumed in 2007 and 2008 across the 36 states (including FCT) of the Federation. Over the years, more than 40.0% of the households did not have access to electricity in the country, 41.4% in 2007 and 48.0% in 2008. This continuous rise in households without access may be connected with rising rates of population growth without corresponding improvements in electricity supply. In 2007, only about 47.3% of the households had access to electricity from Power Holding Company of Nigeria (PHCN), and this figure decreased to 40.4% in 2008. The households depending on self-diesel generating plants rose from 2.7% to 3.2% over the period. Similarly, households complementing power form the national grid with diesel generating plants also rose to 6.3% in 2008 from 5.8% in 2007. It is clearly shown that the rural electrification programme in the country is yet to record a remarkable progress with just 0.9% of household being its beneficiary. Solar energy is yet to be substantially utilized despite the country's solar potential while nuclear energy is still not in use at all.

The ability of the distribution of power system to perform its function under stated conditions for a period of time without failure is called Distribution System Reliability (DSR) [46]. System Average Interruption Duration Index (SAIDI) is one of the DSR indices used in the assessment of distribution performance. It represents in minutes, the annual average total duration of electric power interruption to a customer. This reliability index is embarrassingly high in Nigeria as shown in Table 7. The Manufacturers' Association of Nigeria (MAN) reported Nigeria SAIDI of 60,000 min or greater than, seems to be more realistic as it agreed with a figure of 87,639 min obtained in another independent research [47]. This is in spite of the fact that only about 40% of the 140 million Nigerians have access to electricity [48]. This high SAIDI had resulted to poor per capita electricity consumption of 125 kWh in Nigeria as against those of South Africa, Brazil and China estimated as 4500 kWh, 1934 kWh and 1379 kWh respectively. The major factor responsible for the interruption of electric power in Nigeria is load shedding as a result of inadequate generation.

Table 6
Percentage distribution of households by state and electricity supply, 2007 and 2008.
Source: Ref [45].

State	PHCN only	Rural electrification only	Private generator only	PHCN/Generator	Rural electrification/generator	Solar energy	None
Abia	44.5 [45.7]	0.1 [1.3]	5.9 [6.5]	15.2 [13.5]	0.5 [1.8]	0 [0]	33.8 [31.1]
Adamawa	22.3 [22.6]	0 [0]	1 [3.4]	4.9 [3.9]	0.5 [0.4]	0 [0]	71.4 [69.8]
AkwaIbom	46.3 [40.6]	2.7 [1.7]	3.3 [7.9]	7.6 [5.9]	1.9 [0.2]	0 [0.2]	38.3 [44.6]
Anambra	58 [61.9]	4.1 [0]	0.2 [3]	6.8 [7.9]	0 [2.3]	0 [0]	30.9 [24.4]
Bauchi	38.7 [31.4]	0 [5.3]	0 [0]	2.8 [3.2]	0 [0]	0 [0]	58.5 [60.2]
Bayelsa	10.3 [21.6]	10.1 [23.3]	13.3 [8.6]	5.8 [7.5]	37.8 [12.2]	0.5 [0]	22.2 [36.9]
Benue	15.7 [22.8]	0 [0]	2.8 [4.2]	2.5 [0.9]	0.5 [0.2]	0 [0]	78.6 [72]
Borno	19.4 [15.2]	4.6 [0]	10.6 [3.8]	0.9 [3.6]	0.1 [0]	0 [0.2]	64.5 [77.3]
C/River	54.1 [40.6]	0.5 [0.3]	3.2 [3.4]	1.7 [9]	3.4 [0.3]	0 [0]	37.1 [46.3]
Delta	62.7 [56.8]	0 [0]	2.5 [2.9]	3 [7.5]	1.6 [3.1]	0 [0]	30.2 [29.6]
Ebonyi	14.7 [12.3]	5 [8.3]	5 [3.2]	0.3 [2.5]	1.5 [5.6]	0 [0]	73.5 [68.1]
Edo	80.7 [77.7]	0 [1.9]	1.5 [2]	0.9 [3.2]	0 [0]	0.1 [0]	16.9 [15.2]
Ekiti	56.7 [61]	0 [0]	1.2 [1.6]	0.8 [5.2]	0 [0.2]	0 [0]	41.3 [32.1]
Enugu	45.6 [44.9]	0.2 [0.5]	3.6 [3.6]	5.5 [4.8]	0.3 [0.3]	0 [0]	44.8 [45.8]
Gombe	50.7 [39.5]	0 [0.9]	0 [0.9]	0 [3.4]	0 [0]	0 [0]	49.3 [55.4]
Imo	68.5 [69.5]	1.4 [0.3]	5.2 [4.6]	4.1 [12.8]	0.1 [0.2]	0 [0]	20.8 [12.6]
Jigawa	39.4 [41.6]	0 [0.2]	0.2 [0.2]	0.4 [1.4]	0 [0.2]	0 [0]	60 [56.5]
Kaduna	53.5 [46.2]	0.5 [0.2]	1.2 [1.8]	2.9 [8.2]	0.2 [1.2]	0 [0]	41.8 [42.4]
Kano	59.6 [42.6]	0 [0]	0 [0.3]	0.8 [0.8]	0 [0]	0 [0]	39.6 [56.2]
Katsina	31 [36.2]	0 [1]	0.1 [0.2]	6.8 [2.9]	0.2 [0]	0 [0]	62 [59.7]
Kebbi	44.2 [42.7]	0 [0]	1.5 [0.4]	1.7 [2.5]	0 [0]	0 [0]	52.6 [54.4]
Kogi	52.1 [39.5]	0 [1.7]	2.3 [4.5]	2.4 [5.2]	0.3 [1]	0 [0]	43 [48.1]
Kwara	54.9 [56.4]	0 [0]	1.5 [1.5]	4.7 [3.6]	0.5 [0]	0 [0]	38.3 [38.5]
Lagos	67.3 [57]	0.1 [0]	0.5 [0.9]	30.8 [40.9]	1.1 [0.9]	0 [0]	0.2 [0.3]
Nassarawa	27.7 [21.3]	0 [0.2]	2.2 [2.4]	6.2 [3.6]	0.4 [1.9]	0 [0]	63.6 [70.6]
Niger	42.5 [35.6]	0 [0]	0.3 [6.2]	1.4 [1.6]	0 [0]	0 [0]	55.9 [56.6]
Ogun	71.3 [69.8]	0.4 [0]	0.3 [0.8]	0.9 [8.5]	0.1 [0.3]	0 [0]	27.1 [20.4]
Ondo	58 [50.3]	0 [1.7]	4.3 [3.8]	3.4 [2.2]	5.3 [0]	0 [0]	29 [41.9]
Osun	67.6 [63.6]	1.6 [0]	0.3 [1.2]	0.5 [1.4]	0 [0]	0 [0]	29.9 [33.9]
Oyo	57.3 [47.5]	0.9 [0]	0.2 [5.3]	11.8 [8.2]	0 [0.2]	0 [0]	29.8 [38.8]
Plateau	23.8 [18.8]	2.4 [1.4]	3.3 [5.7]	3.8 [2.1]	1.1 [0.7]	0 [0]	65.6 [71.3]
Rivers	24.6 [41]	7.4 [0.7]	16.3 [13.8]	4.7 [11.9]	10.4 [10.9]	0 [0]	36.6 [21.7]
Sokoto	35.7 [29.8]	0.3 [0]	0.7 [0.2]	0.8 [0.3]	2.3 [0.2]	0 [0]	60.3 [69.5]
Taraba	3.7 [3.8]	0.7 [0]	2.4 [1.2]	1.7 [5.9]	0.3 [1.4]	0.1 [0]	91 [88.8]
Yobe	16.2 [18.1]	0.4 [0.7]	0.1 [0.7]	0.3 [2.1]	0.2 [0.4]	0 [0]	82.9 [78]
Zamfara	24.7 [21.5]	0 [0.2]	0.3 [0.2]	2.4 [0.5]	0 [0]	0 [0.5]	72.7 [77.1]
FCT	36.6 [38.3]	0 [0.3]	11.7 [10.6]	19.8 [23.7]	0.6 [0.2]	0 [0]	31.3 [36.9]
Average	47.3 [40.4]	1.1 [0.9]	2.7 [3.2]	5.8 [6.3]	1.6 [1.1]	0 [0]	41.4 [48]

Table 7
SAIDI for some countries.
Source: Ref. [48].

Country	SAIDI (min)
France	52
Singapore	~15
USA	88
Nigeria (PHCN)	900
Nigeria (MAN Study)	> 60,000

3.2. Power sector goals in Nigeria Vision 20:2020

The Federal Government of Nigeria commenced the reform of the power sector via the enactment of the EPSR Act 2005, as a primary driver towards sustainable and adequate power supply to the country. However, the relatively slow pace of the implementation of this Act has not brought the desired changes in the sector.

As reflected in the Volumes I & II of the 1st National Implementation Plan for Nigeria Vision 20:2020, the strategic context of Power in national development could not be over-emphasized. The broad vision for the power sector is to meet the demand for adequate and sustainable power in all sectors by the Nigerian economy and in all parts of the country at affordable costs. This must be done in a technically efficient, economically viable and environmentally sustainable manner using different energy sources, conventional and non-conventional, to ensure supply at all times with minimal disruption.

The Nigeria's Vision 20:2020 goal is to generate, transmit and distribute 35,000 MW of electricity by the year 2020 [44]. The NV20:2020 strategic objective for the power sector is to ensure that the sector is able to efficiently deliver sustainable, adequate, qualitative, reliable and affordable power in a deregulated market, while optimizing the on and off-grid energy mix. It is expected that the electricity supply industry will ultimately be private sector driven. In this Plan however, government will invest in direct electricity generation as well as provide appropriate legal and regulatory environment for private sector participation. In the medium term, the goal was to generate, transmit and distribute 16,000 MW of electricity by 2013. Specifically, the overall target for the plan period was to increase electricity generation, transmission and distribution from the 3700 MW capacity as at December, 2009 to 8000 MW by 2010, and 16,000 MW by 2013. Access to electricity is expected to increase from the current 40% to 50%, while per capita consumption will increase from the current 125 kWh to 500 kWh over the plan period. This is expected to be achieved through significant investment in rural electrification programmes that will facilitate the expansion of transmission and distribution lines to majority of rural Nigeria. Alternative energy technology will also be developed from Coal and other renewable energy sources (Solar, Wind, and Biomass) will be encouraged to electrify the rural communities. In order to achieve the medium term goal, Government aimed to continue regular maintenance of all power infrastructures, rehabilitate and complete all on-going power projects while putting in place incentives for private sector participation through accelerated implementation of the Power Reforms Act.

4. Rural energy needs in Nigeria

More than 70% of total populations of the country live in rural areas. At present major portion of total energy needs for cooking is met by locally available biomass fuels. The rural electrification programme meets a small portion of total energy needs. For overall national development there is a need to pay special attention so that the energy needs of rural areas for subsistence and productive requirements (e.g. agriculture, industries, and transport) are met on a sustainable basis. Different types of renewable energy technologies such as Solar Home System (SHS), Biogas, and Improved Cooking Stoves (ICS) are suitable for Nigeria.

The situation in the rural areas of the country is that most end users depend on fuel wood. Fuel wood is used by over 70% of Nigerians living in the rural areas. Nigeria consumes over 50 million metric tonnes of fuel wood annually, a rate, which exceeds the growth of plants used for fuel wood. Sourcing fuel wood for domestic and commercial uses is a major cause of desertification in the arid-zone states and erosion in the southern part of the country. The rate of deforestation is about 350,000 ha per year, which is equivalent to 3.6% of the present area of forests and woodlands, whereas reforestation is only at about 10% of the deforestation rate [49].

The rural areas, which are generally inaccessible due to absence of good road networks, have little access to conventional energy such as electricity and petroleum products. Petroleum products such as kerosene and gasoline are purchased in the rural areas at prices 150% in excess of their official pump prices. The daily needs of the rural populace for heat energy are, therefore, met almost entirely from fuel wood. The sale of fuel wood and charcoal is mostly controlled in the un-organized private sector. The sale of kerosene, electricity and cooking gas is essentially influenced and controlled by the Federal Government or her agencies – NNPC in the case of kerosene and cooking gas and the National Power Holding Company (PHCN) for electricity. The policy of the Federal Government had been to subsidize the pricing of locally consumed petroleum products, electricity inclusive. In a bid to make the petroleum downstream sector more efficient and in an attempt to stem petroleum product consumption as policy focus, the government on a number of occasions, reduced and removed subsidies on various energy resources in Nigeria. The various policy options have always engendered price increases of the products [50].

The implications of all these is that the rural dwellers, the urban and even the medium income group people would resort almost fully to the use of fuel wood. This would translate into increased deforestation to source for fuel wood and charcoal which are derived from the forests and are close substitutes to kerosene, cooking gas and electricity as domestic energy resources. Environment Rights Agency observed that massive deforestation of the nation's severely depleted forest may follow if the fuel price of kerosene and cooking gas in the face of unchanged income of consumers, leads to a reduction in real income and decreased demands for these commodities.

For overall national development there is a need to pay special attention so that the energy needs of rural areas for subsistence and productive requirements (e.g. agriculture, industries, and transport) are met on a sustainable basis. Different types of renewable energy technologies such as Solar Home System (SHS), Biogas, Solar water pumping, Solar Street lighting and Improved Cooking Stoves (ICS) are suitable for Nigerian rural dwellers.

4.1. Decentralized energy system

The World Alliance for Decentralized Energy (WADE) defines decentralized energy (DE) as 'electricity production at, or near, the point of use, irrespective of size, technology or fuel used — both off-grid and on-grid' [51]. This includes:

- On-site renewable energy.
- High efficiency cogeneration.
- Industrial energy recycling and on-site power.

The fundamental element of a DE system is where power is generated. DE technologies generate electricity where it is needed. Central generation, on the other hand, generates electricity in

large remote plants, requiring power to be transported over long distances at high voltage before it can be used.

More often than not, DE is synonymous with cleaner electricity — indeed that is one of DE's main benefits. The various renewable DE technologies include:

- Solar photovoltaic panels such as crystalline-silicon technologies and thin-film technologies;
- Roof-top/local wind turbines;
- Small-scale local hydropower, such as small-scale tidal or run-off the river;
- Geothermal energy;
- Renewable energy-powered fuel cells;
- Thermal based technologies, including biomass-fired engines, biomass-fired steam turbines, gas turbines and microturbines;
- Plug-in electric hybrid vehicles.

Renewable DE, fossil-fired DE and energy recycling offer many advantages over conventional power generation. This is true in terms of the environment, the economy, efficiency, as well as security and reliability. This is not just because of how DE technologies generate electricity, but also because of where they generate power. All three types of DE are beneficial because they provide electricity where it is required. Specifically, the advantages of using DE include the following: (i) Optimum use of existing energy infrastructure, (ii) Quick start-up, (iii) Higher overall efficiency and (iv) Environmental benefits.

There is a growing worldwide acceptance that decentralized electric generation will reduce capital investment needs compared to central generation with its supporting transmission and distribution systems. In addition, decentralized generation can lower the cost of electricity, reduce pollution, reduce production of greenhouse gas, increase accessibility to electricity, and decrease vulnerability of the electric system to extreme weather and militants attacks. While DE is unlikely to replace central power entirely, it is believed that the share of DE in global power generation will increase dramatically in coming years, with important benefits to all segments of the population and significant environmental benefits.

Affordable and reliable energy availability is the precondition for sustainable development. The rural population suffers from lack of energy access and affordable energy services. These challenges can be solved by renewable decentralized energy systems. The subsequent sections discussed the potential and benefits of renewable energy towards achieving sustainable development in Nigeria.

5. Energy and sustainable development in Nigeria

Energy is central to practically all aspects of sustainable development. Energy is central to the economy because it drives all economic activities. This characterization of energy directs our attention to its sources in nature, to activities that convert and re-convert this energy, and finally to activities that use the energy to produce goods and services and household consumption. Traditionally, energy is treated as an intermediate input in the production process. This treatment of energy's role understates its importance and contribution to development. All economic activities and processes require some form of energy. This effectively makes energy a critical primary factor of production. Given the state of technological advancement in the economy, capital and labour perform supporting roles in converting, directing and amplifying energy to produce goods and services needed for growth and poverty reduction [52].

Based on this fact, Nigerian energy sector is still characterized by the widespread use of ecologically and economically questionable private diesel generators which account for over 50% of the active generation capacity. The negative consequences are high cost of electricity to business owners/consumers with none or insufficient power services, regular power cuts and high losses of electricity and environmental impact on the society. This in turn poses a huge obstacle to sustainable economic and social development in the country while negatively impacting on environment and poverty reduction.

There is also only limited use of renewable energies for both on-grid and off-grid electrification resulting in poor access to electricity in rural areas. The generally low degree of energy efficiency actually reduces the utilization of the limited capacity even further. The key causes are inadequate technical and managerial capacity, the insufficient provision of investment by both public and private sectors and lack of clear incentives for investment leading to unfavourable framework conditions in the sector.

Use of renewable natural resources combined with efficient supply and use of fossil fuels with cleaner technologies, can help reduce the environmental effects of energy use and help Nigeria grow her economies while also replacing existing, inefficient polluting fossil fuel technologies that pollute the environment.

Much as this may seem enticing, the issue of affordability particularly in respect of the poor cannot be taken for granted. As a complementary measure, careful management of energy resources is important to promote economic growth, protect ecosystems and provide sustainable natural resources.

Thus energy sustainability is considered to involve the sustainable use of energy in the overall energy system. This system includes processes and technologies for the harvesting of energy sources, their conversion to useful energy forms, energy transport and storage, and the utilization of energy to provide energy services such as operating communications systems, lighting buildings and cooking. Thus, energy sustainability goes beyond the search for sustainable energy sources, and implies sustainable energy systems, i.e., systems that use sustainable energy resources, and that process, store, transport and utilize those resources sustainably.

5.1. *Renewable energy resources and potential in Nigeria*

Renewable energy and technologies have great potential to provide solutions to the long-standing energy problems being faced in Nigeria. In promoting the diffusion of renewable energy into the country's energy supply mix for sustainable development, the government approved in November 2005, the Renewable Energy Master plan (REMP). The REMP was prepared by the Energy Commission of Nigeria (ECN) in collaboration with the United Nations Development Programme (UNDP) [53].

In the present predicament as a nation, it is obvious that depending mainly on fossil fuel (petroleum and Natural gas) is not enough to meet the energy needs of the country. Since Nigeria is blessed with abundant renewable energy resources such as hydroelectric, solar, wind, tidal, and biomass (Table 8), there is a need to harness these resources and chart a new energy future for Nigeria. In this regard, the government has a responsibility to make renewable energy technologies available and affordable to all.

Many indigenous researchers have looked into the availability of renewable energy resources in Nigeria with a view to establishing their viability in the country. In this regard, the renewable energy sources that will be considered are solar energy, wind energy, hydropower and biomass.

Table 8
Nigeria's non-conventional energy resources.
Source: [53].

Resources	Reserves	Reserves (billion tonnes)
Fuel wood	43.3 million tonnes	1.6645 (over 100 years)
Animal wastes		
And crop residue	144 million tonnes	3.024 (over 100 years)
Small scale hydropower	734.2 MW	0.143 (over 100 years)
Solar radiation	1.0 kW m^{-2} Land area (peak)	–
Wind	2.0–4.0 m s^{-1}	–

5.1.1. Solar energy

Nigeria lies within a high sunshine belt and, within the country solar radiation is fairly well distributed. The annual average of total solar radiation varies from about 12.6 MJ/m^2-day (3.5 kWh/m^2-day) in the coastal latitudes to about 25.2 MJ/m^2-day (7.0 kWh/m^2-day) in the far north. Assuming an arithmetic average of 18.9 MJ/m^2-day (5.3 kWh/m^2-day), Nigeria therefore has an estimated 17,459,215.2 million MJ/day (17.439 TJ/day) of solar energy falling on its 923,768 km^2 land area. Annually, the above average solar intensity is 6898.5 MJ/m^2-year or 1934.5 kWh/m^2-year. This gives an impression that implementing solar energy strategy is a great opportunity for Nigeria to get renewable energy at low cost as well as minimize dependence from fossil fuels.

According to Oji et al. [54], the total radiation received per day on a 1 m^2 surface at Ibadan (Western part of Nigeria) varies from 16 MJ in January to 22 MJ in May. Under the same period at Kano (Northern part of Nigeria) the total radiation received varies from 33 MJ to 37 MJ per day on the same surface. Using this as a benchmark, it can be seen that even the minimum harnessible power in any part of the country is more than that required for powering an average 3-bed room flat and 2-room apartment using low-power consuming appliances. The need for harnessing this renewable energy supply is apparent as fossil fuels (especially oil) become increasingly expensive, depleting reserves, population increase, and individual press for a higher standard of living in terms of material goods, especially in rural and developing regions.

Onyebuchi [55] estimated the technical potential of solar energy in Nigeria with a 5% device conversion efficiency put at 15.0×10^{14} kJ of useful energy annually. This equates to about 258.62 million barrels of oil equivalent annually, which corresponds to the current national annual fossil fuel production in the country. This will also amount to about 4.2×10^5 GW/h of electricity production annually, which is about 26 times the recent annual electricity production of 16,000 GW/h in the country.

Solar radiation conversion technologies are generally either of the solar-thermal type (solar heating, cooling, drying, thermal power plant, etc.) or of the photovoltaic type (direct conversion to electricity). Areas of application of solar thermal technologies are crop drying, house heating, heating of process water for industries, hospitals etc., air-conditioning, preservation of foods and drugs, power generation, etc. Photovoltaic (PV) power may be utilized in low to medium power applications and in remote areas, in such uses as communication stations, rural television and radio, water pumping, refrigeration etc., which require power of the order of 1–10 kW. It may also be used for power supply to remote villages not connected to the national grid. It is also possible to generate PV power for feeding into the national grid.

Several pilot projects, surveys and studies have been undertaken by the Sokoto Energy Research Center (SERC) and the National Center for Energy Research and Development (NCERD) under the supervision of the ECN. Several PV-water pumping, electrification, and solar-thermal installations have been put in place. Such Solar thermal applications include solar cooking, solar crop drying, solar incubators and solar chick brooding. Other areas of application of solar electricity include low and medium power application such as: water pumping, village electrification, rural clinic and schools power supply, vaccine refrigeration, traffic lighting and lighting of road signs.

Most solar-thermal technologies can be supported by the technical expertise existing within the country. However the industrial infrastructure needs to be strengthened for effective utilization of the energy resource. Photovoltaic system components require more sophisticated technologies for their manufacture, particularly as regards the photovoltaic cells.

5.1.2. Wind power

In Nigeria, wind energy reserves at 10 m height shows that some sites have wind regime between 1.0 and 5.1 m/s. The wind regimes in Nigeria are classified into following four regimes >4.0 m/s; 3.1–4.0 m/s; 2.1–3.0 m/s; and 1.0–2.0 m/s. Hence, Nigeria falls into the moderate wind regime. It is also observed that the wind speeds in the country are generally weak in the South except for the coastal regions and offshore, which are windy. In the coastal areas and in the large areas offshore from Lagos State through Ondo, Delta, Rivers and Bayelsa States to Akwa Ibom State, potentials exist for harvesting strong wind energy throughout the year.

Except for maritime activities and fishing, there is hardly any obstacle to wind farm development for near-shore wind energy farms. Inland, the wind is strongest in the hilly regions of the North. The mountainous terrains, especially in the middle belt and the northern fringes of the country, where prime wind conditions exist, are to a large extent sparsely populated, and extensive areas for wind energy development exist in these locations.

Moreover, many indigenous researchers have also explored the availability of wind energy sources in Nigeria with a view of implementing them if there is likelihood for their usage [56–58]. Each of these researchers point to the fact that the nation is blessed with a vast opportunity for harvesting wind for electricity production, particularly at the core northern states, the mountainous parts of the central and eastern states, and also the offshore areas, where wind is abundantly available throughout the year.

At present, the share of wind energy in the national energy consumption has remained on the lower end with no commercial wind power plants connected to the national grid, Only a few number of stand-alone wind power plants were installed in the early 1960s in 5 northern states mainly to power water pumps and a 5 kW wind electricity conversion system for village electrification installed at Sayyan Gidan Gada, in Sokoto State.

The issue then is for the country to look at ways of harnessing resources towards establishing wind farms in various regions and zones that have been identified as possessing abilities for the harvesting of wind energy.

5.1.3. Hydro

Essentially, hydropower systems rely on the potential energy difference between the levels of water in reservoirs, dams or lakes and their discharge tailwater levels downstreams. The water turbines which convert the potential energy of water to shaft rotation are coupled to suitable generator [59]. Nigerian's Hydropower Potential is high and hydropower currently accounts for about 32% of the total installed commercial electric power capacity.

Nigeria has considerable hydro potential sources exemplified by her large rivers, small rivers and stream and the various river basins being developed. Nigerian rivers distributed all over the country with potential sites for hydropower scheme which can serve the urban, rural and isolated communities. An estimation of river Kaduna, Benue and Cross River (at Shiroro, Makurdi and Ikom respectively) indicated that total capacity of about 4650 MW is

available, while the estimate for the river Mambillla plateau is put at 2330 MW. Large number of untapped hydropower potential sites was identified by Motor Columbus in the 1970s. Akinbami [60] and Sambo [59] reported that the total hydropower resources potentially exploitable in Nigeria was estimated to be about 11,250 MW with an annual electricity generation potential in excess of 36,000 GWh. This consists of 10,426 MW of large hydropower technology, while the remaining 824 MW is still small-scale hydropower technology. Presently, 24% and 4% of both large and small hydropower potentials, respectively, in the country have been exploited.

Indeed small-scale (both micro and mini) hydropower systems possess the advantage over large hydro systems, that problems of topography are not excessive. In effect, small hydropower systems can be set up in all parts of the country so that the potential energy in the large network of river can be tapped and converted to electrical energy. In this way the nation's rural electrification projects can be greatly enhanced.

5.1.4. Biomass energy

Biomass energy refers to the energy of biological systems such as wood and wastes. Biomass is an indirect form of solar energy because it arises due to photosynthesis. Identified biomass resources in Nigeria include: wood, forage grasses and shrubs, animal waste, agricultural and forestry residue, municipal and industrial waste, as well as aquatic biomass [61,16]. Biomass materials can be transformed into fuel briquettes, a cleaner source of fuel than direct combustion for both domestic and industrial uses. They can also be converted into cooking gas (which is a completely clean energy) in biogas digesters. Energy plants like Jatropha, sugarcane and maize are proven sources of clean biofuel. Nigeria has abundant biomass resources for full-scale exploitation. About 80 million cubic metres (43.4×10^9 kg) of fuel wood is consumed annually in Nigeria for cooking and other domestic purposes [59]. In addition, intense demand for wood by construction and furniture industries are aiding the depletion of Nigeria's biomass. Forage grasses and shrubs produce 200 million tons of dry biomass, which give up to 2.28×10^6 MJ of energy.

Similarly, crop residues and waste produce estimates of 6.1 million tons of dry biomass with energy content approximate to 5.3×10^{11} MJ. Nigeria's forestland is about 9,041,000 ha, which is 9.9% of its total landmass. Meanwhile, 1985 estimates suggested that animals and poultry produced 227,500 t of waste with energy content of 2.2×10^9 MJ when converted to biogas. Estimates show that this is of the order of 5.36×10^9 m^3 which has an energy content amounting to 2.93×10^9 kWh.

The foregoing shows that there is a huge potential for production of agricultural biomass in Nigeria. A sizeable proportion of Nigerian households are engaged in crop farming and livestock farming respectively. Biomass, which essentially comprises wastes produced from these activities are already available.

Current effort by the Nigerian government to improve biomass utilization is majorly in the transportation sector. The 2007 bioethanol policy birthed the 10% ethanol inclusion into petroleum products in the country. Present estimates show that around 61 million tonnes/year of animal waste can be achieved and that about 83 million tonnes/year of crop residue can be obtained. The government can extend the use of bioethanol into power generation which will produce significant effect since the feed stocks for bioethanol are renewable. The estimate of biomass contribution to power generation in Nigeria is not available.

5.2. Demand side energy management

Electricity, even at current levels of generation can be made to go round a higher proportion of Nigerians (coverage presently put at 40%), if efficiency and conservation standards are embraced by the consumers [62].

By extension, the cost of power to the consumer could fall drastically in the face of prudent demand side management. It is compelling therefore to promote at all levels electricity efficiency and conservation in the Nigerian Power Sector. Issues of energy security and self-sufficiency and the possible adverse impacts of electricity utilization on the environment support the global call for conservation and efficient consumption in sustainable electricity supply.

Presently, energy utilization in Nigeria is far from being efficient. Apart from the direct loss due to energy wasted, using energy inefficiently has three major implications in Nigeria. These are:

- The investment in some energy supply infrastructure is far in excess of what the energy demand is;
- The environmental problems associated with energy utilization are more aggravated due to large energy consumption; and
- Excessive energy consumption adds costs to the costs of goods produced especially in energy intensive industries like cement, steel works and refineries.

The potential for energy savings is substantial in the three most energy consuming sectors of the economy namely household, industry and transportation. In the household sector, for example, there is considerable energy loss due to the use of inefficient traditional three stone stoves with efficiencies of between 5% and 12% [59]. Efficiencies three times that can be obtained with the use of improved fuel wood stoves. Also, in the household sector substantial savings of energy can be made by switching over from incandescent bulbs to fluorescent lamps. In the industrial sector energy audit studies have shown that up to 25% of energy consumption can be saved by adopting simple housekeeping measures [63]. Such measures include putting off electrical machinery on no-load condition, plugging steam leaks and avoiding material wastages. Also, our transport sector has substantial opportunities for savings, most especially the road transport subsector. Much savings can be realised by emphasizing mass transit schemes and restricting importation of second hand vehicles (a.k.a 'Tokunbo') that are inefficient.

It is therefore imperative to promote energy conservation and efficient energy utilization in all sectors of the economy.

The major barriers militating against adoption of more energy efficient practices in Nigeria can be identified as follows:

- Lack of awareness of the potential and importance of energy efficiency;
- Lack of skilled manpower to carry out energy audit studies;
- Lack of awareness of potential alternatives such as renewable energy technologies.

In Nigeria, the prominent areas of opportunities for energy conservation generally and particularly in office and residential buildings, industrial set-up/manufacturing processes are facilities such as: Ventilating air-conditioning equipment for space cooling, (HVAC); Lighting and illuminating devices; Power generating machines for electrically operated equipment, such as pumps, Fans and Domestic water heating appliances etc.

For improved demand side energy management in Nigeria, the following steps are very essential to be taken by the government, industrialists and every Nigerian:

(i) Ensure the importation of energy-efficient motor vehicles, equipment and machinery.
(ii) Import transformers that are rugged enough to function when overloaded to accommodate the peculiarities of the Nigerian Power System.

(iii) Intensify R&D efforts in increasing local content materials in the design and construction of energy efficient buildings.
(iv) Develop and implement an equipment power labelling programme.
(v) Screen imported electrical appliances to control the quality of energy-efficient products imported into Nigeria.
(vi) Strengthen agencies responsible for ensuring the quality of importation and local production of standard equipment and spare parts.
(vii) Establish a specialized local content development equipment laboratory to encourage the production of electricity equipments and tools in Nigeria.
(viii) Put in place measures to cut down on electricity transmission and distribution losses. The present 40% loss level should not be tolerated any longer.
(ix) Adopt a tariff structure and other schemes which promote Demand and Supply Side Management of electricity consumption.
(x) Embark on studies on Supply Side Management and Demand Side Management for the power sector to bring down electricity transmission and distribution losses.
(xi) Educate the public using the print and electronic media on the benefits of energy efficiency practices and equipment.

6. Energy policy

Energy policy is the manner in which a nation has decided to address issues of energy development including energy production, distribution and consumption. The attributes of energy policy may include legislation, international treaties, incentives to investment, guidelines for energy conservation, taxation and other public policy techniques.

A comprehensive and coherent energy policy is essential in guiding a country towards efficient utilization of its energy resources. However, the existence of an energy policy, while crucial, does not guarantee prudent management of a country's energy resources.

6.1. The National Energy Policy in Nigeria

The Nigerian National Energy Policy was last reviewed in April 2003. Before 2003, the country had no comprehensive energy policy. It did have separate policy documents for different energy sub-sectors: electricity, oil, gas and solid minerals. Prior to 2003, there was no consideration whatsoever for the inclusion of renewable energy sources in the national energy mix. The 2003 Energy Policy document, for the first time, included elements of renewable energy planning, though in a cursory manner.

The National Energy Policy developed by the Energy Commission of Nigeria was to serve as a blueprint for the sustainable development, supply and utilization of energy resources within the economy, and for the use of such resources in international trade and co-operation.

The key objectives of the National Energy Policy are:

- To ensure the development of the nation's energy resources, with a diversified energy resources option, for the achievement of national energy security and an efficient delivery system with an optional energy resource mix.
- To guarantee increased contribution of energy productive activities to national income.
- To guarantee adequate, reliable and sustainable supply of energy at appropriate costs and in an environmentally friendly manner, to the various sectors of the economy, for national development.
- To guarantee an efficient and cost effective consumption pattern of energy resources.
- To accelerate the process of acquisition and diffusion of technology and managerial expertise in the energy sector and indigenous participation in energy sector industries, for stability and self-reliance.
- To promote increased investments and development of the energy sector industries with substantial private sector participation.
- To ensure a Comprehensive, integrated and well informed energy sector plan and programmes for effective development.
- To foster international co-operation in energy trade and projects development in both the African region and the world at large.
- To successfully use the nation's abundant energy resource to promote international cooperation.

6.2. Trends in renewable energy promotion policies

The need for enacting policies to support renewable energy is often attributed to a variety of barriers, or conditions that prevent investments from occurring. Often the result of barriers is to put renewable energy at an economic, regulatory, or institutional disadvantage relative to other forms of energy supply. Barriers include subsidies for conventional forms of energy, high initial capital costs coupled with lack of fuel-price risk assessment, imperfect capital markets, lack of skills or information, poor market acceptance, technology prejudice, financing risks and uncertainties, high transactions costs, and a variety of regulatory and institutional factors. Many of these barriers could be considered market distortions that unfairly discriminate against renewable energy, while others have the effect of increasing the costs of renewable energy relative to the alternatives.

This section explains the policies currently available and in use around the world to support renewable energy (RE) technologies—from their infant stages, to demonstration and pre-commercialization, and through to maturity and wide-scale deployment—in order to enable RE to play a significant role in mitigating climate change and afford access to modern and clean energy services. This section focuses on policies directly supporting RE, based on the assumption that policymakers are aiming to increase RE levels based on drivers of their choosing.

Until the early 1990s, few countries had enacted policies to promote RE. Since then, and particularly since the early- to mid-2000s, policies have begun to emerge in a growing number of countries at the municipal, state/provincial, national and international levels. Initially, most policies adopted were in developed countries, but an increasing number of developing countries have enacted policy frameworks at various levels of government to promote RE since the late 1990s and early 2000s [64].

Policies whose specific goal is to promote renewable energy fall into four main categories: (1) price setting and quantity-forcing policies, which mandate prices or quantities; (2) investment cost reduction policies, which provide incentives in the form of lower investment costs; and (3) public investments and market facilitation activities, which offer a wide range of public policies that reduce market barriers and facilitate or accelerate renewable energy markets and (4) renewable energy target setting, provides planning certainty and helps to create an environment that is favourable to long-term investments.

6.2.1. Price-setting and quantity-forcing policies

Price-setting policies reduce cost- and pricing-related barriers by establishing favourable pricing regimes for renewable energy

relative to other sources of power generation. The quantity of investment obtained under such regimes is unspecified, but prices are known in advance. Quantity-forcing policies do the opposite; they mandate a certain percentage or absolute quantity of generation to be supplied from renewable energy, at unspecified prices. Often price setting or quantity-forcing policies occur in parallel with other policies, such as investment cost'-reduction policies [65].

The two main price-setting policies seen to date are the PURPA legislation in the United States and electricity feed-in laws in Europe. The quantity forcing policies include: Renewable Energy (Green) Certificates, Renewable Energy Portfolio Standards (RPS), Competitively-Bid Renewable-Resource Obligations and Mandatory Market Share (MMS) policy or Quotas.

PURPA was enacted in 1978 in part to encourage electric power production by small power producers using renewable resources to reduce U.S. dependence on foreign oil. The policy required utilities to purchase power from small renewable generators and co-generators, known as qualifying facilities, through long-term (10-year) contracts at prices approximating the avoided costs of the utilities [66].

The electricity feed-in laws in Germany, and similar policies in other European countries in the 1990s, set a fixed price for utility purchases of renewable energy. For example, in Germany starting in 1991, renewable energy producers could sell their power to utilities at 90% of the retail market price. The utilities were obligated to purchase the power. The German feed-in law led to a rapid increase in installed capacity and development of commercial renewable energy markets [67].

Renewable Portfolio Standard (*RPS*), *Renewables Obligation* (*RO*), *Mandatory Market Share* (*MMS*) *policy or Quotas* are the different names given to a similar set of incentives for RE in various countries, RPS in USA, RO in UK, MMS in China and renewable quotas in European countries [68]. The shared theme of all these incentives is that the government sets a percentage of electricity to be generated by renewable sources, assigns an actor, such as electricity users, suppliers or generators, to meet the specific percentage and penalizes those who fail to meet their goals. These mechanisms are essentially market based and they are designed to achieve a cost-efficient generation of RE. Quotas are presently applied in a number of countries around the world. The RPS in Texas has been very effective due to good local resource, presence of tax credits and strong penalties for non-compliance.

Renewable energy (*green*) *certificates* are emerging as a way for utilities and customers to trade renewable energy production or consumption credits in order to meet obligations under RPS and similar policies. Standardized certificates provide evidence of renewable energy production and are coupled 'with institutions and rules for trading that separate renewable attributes from the associated physical energy. This enables a paper market for renewable energy to be created independent of actual electricity sales and flows.

Public and private institutions are emerging that keep track of renewable energy generation, assign certificates · to generators, and register trades and sales of certificates. Green certificate trading is gaining ground in the UK, Belgium, Denmark, Australia, and the United States. Europe embarked on a test phase of an EU-wide renewable energy certificate trading system during 2001 and 2002 [69].

6.2.2. Cost-reduction policies

A number of policies are designed to provide incentives for voluntary investments in renewable energy by reducing the costs of such investments. These policies can be characterized as falling in five broad categories: policies that: (1) reduce capital costs up front (via subsidies and rebates), (2) reduce capital costs after purchase (via tax relief), (3) offset costs through a stream of payments based on power production (via production tax credits), (4) provide concessionary loans and other financial assistance, and (5) reduce capital and installation costs through economies of bulk procurement.

The high upfront investment cost of renewable energy technologies makes them unattractive choices for investors. Removing this barrier by reduction in the initial capital outlay by consumers for RE systems is accomplished through direct subsidies or rebates. These subsidies are used to share the initial capital cost of the system, so that the consumer sees a lower price. Subsidies have been used by many countries for stimulating growth in RE sector. A combination of investment subsidies, low-interest loans, net metering and public education has resulted in an early success of PV in Japan [69]. Similar subsidies have been employed in many countries for RE development [70]. In most cases, they are used in combination with other RE support mechanisms. This is in stark contrast with investment tax credits, which tend to favour large companies with greater tax liabilities.

6.2.3. Public investments and market facilitation activities

Public finance mechanisms have a twofold objective: to directly mobilize or leverage commercial investment into RE projects, and to indirectly create scaled up and commercially sustainable markets for these technologies. Public finance policies are designed such that their direct short-term benefits do not create market distortions that indirectly hinder the growth of sustainable, long-term markets [71].

Loans and other public finance policies have been used to advance deployment of RE electricity technologies, for PV in Spain, for example. Concessionary loans, guarantees and even equity investments have been used frequently in other contexts as well, including in developing countries. Government procurement is also an option that is of increasing significance in some countries, including the USA. For example, the US Energy Policy Act of 2005 requires federal agencies to obtain 7.5% of their electricity needs from renewable sources by 2013 and thereafter [72]. In addition, many US state and local governments have made voluntary commitments to purchase renewable electricity for government facilities [73].

In general, the funds from public investment serve a variety of purposes, such as paying for the difference between the cost of renewables and traditional generating facilities, reducing the cost of loans for renewable facilities, providing energy efficiency services, funding public education on energy-related issues, providing low-income energy assistance, and supporting research and development.

Market facilitation supports market institutions, participants, and rules to encourage renewable energy technology deployment. A variety of policies are used to build and maintain this market infrastructure, including policies for design standards, accelerated siting and permitting, equipment standards, and contractor education and licensing. Additionally, policies to induce renewable technology manufactures to site locally and direct sales of renewable systems to customers at concessionary rates facilitate market development [74].

6.2.4. Renewable energy target setting

According to the Renewable Energy Policy Network for the 21st Century (REN21), which is believed to be the only source that tracks RE policies annually on a global and comprehensive basis, the number of countries with some kind of RE target and/or deployment policy related to RE almost doubled from an estimated 55 in early 2005 to more than 100 in early 2010 [75].

By early 2010, at least 85 countries, including all 27 EU member states, had adopted RE targets at the national level—for specific shares of electricity, or shares of primary or final energy from RE; sub-national targets exist in a number of additional countries.

National renewable energy targets (also referred to as goals) have emerged as a political context for promoting specific combinations of policies. Such targets focus on the aggregate energy production of an entire country or group of countries. Targets may specify total primary energy from renewables or minimum renewable energy shares of electricity generation.

Several countries have adopted or are proposing national renewable energy targets. In 2010, the European Union collectively adopted a target of 22% of total electricity generation from renewables with individual member states having individual targets above or below that amount. In 2010, Japan adopted a target of 3% of total primary energy. Legislative proposals in the United States require 10% of electricity generation from renewables by 2020. Russia adopted a target of 4.5% of all electricity generation and consumption from renewable sources by 2020 [76]. China and India are the first developing countries to propose renewable energy targets. India is aiming for 15% of power capacity, 10% of oil consumption to be substituted and 100% use of solar hot water in all possible applications by 2032; while China has set a target of 16% of primary energy to come from renewable sources by 2020 [77]. In 2011, Thailand announced a target of 8% of primary energy to come from renewable sources. Other countries with existing or proposed targets are Australia, Brazil and Malaysia.

Setting clear and ambitious targets for the use of renewable energy sources provides planning certainty and helps to create an environment that is favourable to long-term investments. Ideally, there should be an overall target for renewable energy use that is then broken down to sector-specific targets for renewable electricity, heat and liquid fuels.

If renewable energy targets are not supported by effective measures, the risk of non-compliance is high. If targets are neither mandatory nor properly enforced, there is tendency of damaging investors' confidence in the government's policy commitments.

6.3. The policy framework on renewable energy in Nigeria

The Federal Government approved the National Energy Policy (NEP) in 2003 to articulate the sustainable exploitation and utilization of all viable energy resources. The policy is hinged on private sector development of the energy sector.

The overall thrust of the National Energy Policy (NEP) is the optimal utilization of the nation's energy resources for sustainable development [16]. The policy identifies renewable energy as one of the sub-sectors of the nation's energy sector, along with oil, natural gas, tar sands, coal and nuclear energy. This is a significant point because it shows that the policy acknowledges the fact that renewable energy is situated within the context of a bigger picture – the energy sector. For a renewable energy plan to be totally effective, it must be steeped in an equally effective national energy policy.

The key elements in the national policy position on the development and application of renewable energy and its technologies are as follows:

- To develop, promote and harness the Renewable Energy (RE) resources of the country and incorporate all viable ones into the national energy mix.
- To promote decentralized energy supply, especially in rural areas, based on RE resources.
- To de-emphasize and discourage the use of wood as fuel.
- To promote the use of alternative energy sources to fuel wood.
- To promote efficient methods in the use biomass energy resources.
- To promote biomass as an alternative energy resource especially in the rural areas.
- To keep abreast of international developments in RE technologies and applications.

Despite the fact that Nigeria is endowed with abundant renewable energy resources, the utilization for the benefit of the development of the people, particularly for the purpose of electricity generation and the economy at large is limited. The increase in new power generation capacity from Power Holding Company of Nigeria (PHCN) and Independent Power Producers (IPPs) has been marginal. This situation is believed to be as a result of lack of adequate policies to drive private investment, particularly policies on renewable energy (RE). Presently there are several unfinished policies that require completion and harmonization, resulting in gaps in the overall implementation of some aspects of the reform e.g. development of renewable energy projects by private investors and involvement of private sector in rural electrification. All these have led to overall minimal investment in new generation, transmission and distribution capacities.

The limited use of renewable energies for both on-grid and off-grid electrification has resulted in poor access to electricity in rural areas. The key causes are inadequate technical and managerial capacity, the insufficient provision of investment by both public and private sectors and lack of clear incentives for investment leading to unfavourable framework conditions in Nigerian power sector.

Based on this the power sector in Nigeria is still characterized by the widespread use of ecologically and economically questionable private diesel generators which account for over 50% of the active generation capacity. The negative consequences are high cost of electricity to business owners/consumers with none or insufficient power services, regular power cuts and high losses of electricity and environmental impact on the society. This in turn poses a huge obstacle to sustainable economic and social development in Nigeria while negatively impacting on environment and poverty reduction.

Achieving adequate energy supply where renewables play a role necessitates the creation of appropriate policy framework of legal, fiscal and regulatory instruments that would attract domestic and international investments.

In Nigeria, renewable energy development has been sporadic in the absence of a comprehensive framework to plan, coordinate and implement a national policy and strategy. Moreover, there is no clear and consistent institutional framework to address barriers and create expanded opportunities for renewable energy technologies. Recently, several ad hoc initiatives had been undertaken by various governmental and non-governmental organizations. Such organizations include: the Energy Commission of Nigeria (ECN), the Federal Ministry of Environment (FME), The One Sky Network, etc. The FME has initiated The Renewable Energy Master Plan Project for Nigeria. The One Sky Network has been organizing workshops and seminars in order to sensitize Nigerians on the benefits of Renewable Energy and thus promoting the use of renewable energy in Nigeria. The ECN has a few technology-driven pilot projects on solar PVs, two wind power demonstration projects located in Sokoto, and a small hydro plant that has been operating in Jos for several years. Nevertheless vast opportunities for small hydro remain untouched [16]. Recently several state governments have embarked on solar projects for rural water supply, residential lighting and lighting of clinics, schools and community centers. These and several other contemplated initiatives suffer from the specific barriers such as: Legal, Policy and

Regulatory Framework, Non-existing Structure for Power Purchase Agreements, lack of Institutional Framework etc

As earlier discussed in Section 6.2, many countries have renewable energy targets that may extend for short, medium or long time. For example, Japan has 3% total energy production from RE; Brazil has 5% power production from RE; India has 4% power production from various RE sources; Australia targets 20% of electricity generated to be sourced from renewable sources by 2020; Egypt has 10% RE production currently, and is expected to be doubled in the year 2020. Nonetheless, Nigeria has a 0% RE share currently and is targeting 7% in 2025 [78]. Stimulatory measures to promote RE service provision among public and private investment are to be put in place as it is done in the above mentioned countries.

Establishment of off-grid generation /distribution plants is to be encouraged by the government through the offer of

- moratorium on import duties for RE technologies;
- design of further tax credits, capital incentives and preferential loan opportunities for RE projects;
- feed-in Tariffs for SHP, solar and wind energy.

6.4. *Energy efficiency policy in Nigeria*

The national Energy Policy and the draft energy master-plan contain basic policies and strategies for energy efficiency and conservation in Nigeria. In specific terms the policy provides for:

- The promotion of energy efficiency and conservation in industrial, residential and transport sectors.
- Designing a National Programme on Industrial Energy Efficiency and Conservation in collaboration with MAN and experts in higher institutions and research centres.
- Introduction of fuel efficiency labelling programme in the transportation sector for various vehicle types.
- Establishing Codes and Standards for energy efficiency and conservation technologies.
- Enforcing the Codes and Standards.

This policy is only on paper but never implemented so as to promote practice of energy efficiency and energy conservation principle in the country.

7. Strategy for delivering access to basic modern energy

Access to basic modern energy services means the ability to satisfy basic energy needs through the use of reliable, efficient, affordable and environmentally friendly modern energy services. Possible strategies for delivering access to basic modern energy in Nigeria are highlighted below.

7.1. *Embarking on energy security and mix*

Nigeria's energy mix should be very diverse to cope with rising fuel demands and assure security of supplies. On the long term, weather dependent contributors like wind power should be developed while strengthening the weather – independent sources like thermal, necessary for a balance mix of energy sources. The interplay of various types of energy – large and small facilities, including hydro electric power, thermal power status and additive renewable energy sources should be exploited for a robust energy mix.

It is important that a full energy mix should be considered for poor communities, such as grid and non-grid solutions for electricity supply, liquid and gas fuels for cooking and biomass wherever it is appropriate; with different emphasis according to location and opportunities. For urban inhabitants, grid extension for electricity supply and liquid and gas fuels for cooking are the most appropriate solutions, though in many cases biomass for cooking in smaller towns may still be required. For rural inhabitants, the most appropriate options may be a combination of grid for those living close to the transmission lines, with decentralized renewable energy options (including microhydro, solar PV and small wind) for off-grid electricity supply. For cooking in rural areas, biomass is likely to remain the main fuel option for the majority, but using more efficient and cleaner cooking devices.

7.2. *Decentralized energy system*

Renewable Energy can enhance access to reliable, affordable and clean modern energy services. It is particularly well-suited for remote rural populations, and in many instances can provide the lowest cost option for energy access [79,80]. Many developing countries—including Bolivia, Bangladesh [81], Brazil [79], China, India [82], Pakistan, Tonga, South Africa and Zambia [83]—have adopted RE policies, such as connection targets and subsidies, in order to provide access to energy services in rural areas.

The use of decentralized renewable electricity is a promising way to meet the demand for basic energy needs in Nigeria, especially among the rural dwellers. Such systems – which include, for example, solar home systems, small wind and mini-hydro, and portable solar lanterns – do not require installation of costly transmission lines and are becoming increasingly affordable thanks to improved economies of scale as a result of the growing number of users and technical improvements. In addition, decentralized systems are more likely to be manufactured and/or repaired locally and are hence, less dependent on foreign technical assistance, strengthening the sustainability of rural livelihoods.

7.3. *Available and possible energy options*

Simple and effective technologies are available to deliver clean and efficient energy to energy poor communities, both in remote rural settings and in towns and cities. Alongside conventional means of rural electrification and fossil fuels (such as LPG or diesel generators), decentralized technologies which use local energy resources, technologies such as micro-hydropower, improved cook stoves, wind turbines and solar power can effectively supply the energy necessary for economic growth and poverty reduction. Over the past 10 years Practical Action has pioneered these technologies, and demonstrated how they can change the lives and economic opportunities for some of Nigeria's poorest people.

While solar PV is useful for some specific applications, such as battery charging, lighting and communications, it should be noted that solar PV is not the only solution for off-grid electricity access. It can also be costly and provide a limited power supply. Over-emphasis on the provision of solar PV, driven by international multilateral corporations, has meant that other viable and cost-effective technologies; such as small scale wind, micro-hydro and biomass, which can be locally developed and manufactured, are hugely neglected and seem to 'fail' because there are limited resources available for their development beyond the pilot phase.

7.4. *Sustainable solutions*

The long-term sustainability of energy access programmes for the poor has been one of the most important issues during the last two decades, especially with regard to small decentralized energy systems for rural electrification and access to efficient biomass cook stoves. Practical Action has used a straightforward strategy of

identification of barriers, and the proposition and implementation of solutions. Through this strategy Practical Action has addressed the issues of affordability and sustainability of energy services and technologies for green economic growth and development.

Practical Action believes that besides the conventional involvement of the private sector in energy businesses, there is a good opportunity for the mobilization of small private resources and local capital towards increasing energy access for development. As well as companies, the private sector is made up of small farmers and local traders, who are looking for investment opportunities in small local businesses. If a level playing field existed, they could also consider the potential business opportunity of energy supply, and they could reach the poor and the isolated more effectively than conventional private energy investors or government. However the mobilization of local capital is only possible with strong, long term commitment from governments and development agencies, enshrined in regulations, incentives (subsidies), and support for local capacity and energy literacy amongst energy consumers.

7.5. Research and development

It is imperative to intensify research and development in the energy sector, especially renewable energy to increase energy sources and improve energy management systems that will promote sustainable development.

The existing Research and Development centres and technology development institutions should be adequately strengthened to support the shift towards increased renewable energy utilization. Human resource development, critical knowledge and know-how transfer should be in focus for projects development, project management, monitoring and evaluation. Preparation of standards and codes of practices, maintenance manuals, life cycle costing and cost-benefit analyses tools to be undertaken on urgent priority.

7.6. Increase funding in energy sector

There should be increased funding in energy sector, which is capital intensive and requires huge amount of investment. The public and private sector could form a partnership to tackle this investment problem.

Government should also increase the budgetary allocation to the energy sector and release these funds duly.

7.7. Energy efficiency and conservation measures

Energy efficiency (EE) means an improvement in practices and products that reduce the energy necessary to provide services. Energy efficiency products essentially help to do more work with less energy. Investments in EE result in long-term benefits, such as reduced energy consumption, local environmental enhancement, and overall economic development. Energy use has environmental impacts, regardless of the source or mechanism.

Energy efficiency has become the key driver of sustainable development in many economies in the world. If we use energy efficiently, it will help to reduce the building of more power stations. Thus, the money for building power stations will then be spent on other sectors of the economy. Moreover, more people will have access to energy; if we save energy in one part of the country, the energy saved can be made available in another part. In Nigeria, where the utility companies do not have enough energy to meet the needs of everybody at the same time, energy supply is alternated. With good energy management at the residential, public, and private sectors, there will be no need to alternate electricity supply.

In Nigeria, the efficiency of utilization of biomass in traditional systems is very low. A large amount of biomass can be saved annually in Nigeria by employing improved (i.e. more efficient) cooking stoves, furnaces, boilers and other devices consuming biomass fuels. The traditional mud cooking stoves used in Nigeria exhibit overall efficiencies of only between 5% and 10%. Hence, large quantity of fuel wood is being consumed. The fuel wood can be conserve and indirectly the environment can be protected with the use of improved and efficient cooking stoves.

8. Conclusions

Affordable and reliable energy availability is the precondition for sustainable development. Sustainable development calls for an efficient, reliable and decentralized energy economy, based on local and clean energy sources, in which the price paid by the consumer will reflect the real cost of energy products to the economy.

There is clear evidence that Nigeria is blessed with abundant resources of fossil fuels as well as renewable energy resources. The major challenge is inefficient utilization of energy in the country. As a result, there is urgent need to encourage the evolvement of an energy mix that will emphasize the conservation of petroleum resources in such a manner that will lead to their continued exportation for foreign earnings for as many years to come as possible. The adoption of renewable energy technologies in a Decentralized Energy (DE) manner especially for rural communities and in stand-alone applications will surely lead to reduced internal consumption of petroleum products.

From the energy outlook of Nigeria, it is very clear that energy demand is very high and is increasing geometrically while the supply remains inadequate, insecure, and irregular and is decreasing with the years; the mix has hitherto been dominated by fossil sources which are fast being depleted apart from being environmentally non-friendly. The energy supply mix must thus be diversified through installing appropriate infrastructure and creating full awareness to promote and develop the abundant renewable energy resources present in the country as well as to enhance the security of supply.

In a bid to attract and encourage renewable energy technologies development in Nigeria, the government needs to put in place the necessary mechanisms that will aid renewable energy development and production in Nigeria. One of the challenges of this effort is the absence of a legal framework to regulate the industry. National government policies formulated for the development of RE sources were outlined in this study. Many of the Government of Nigeria energy initiatives are merely green paper policies that lack the resolve to be taken into the implementation realm. To facilitate greater uptake of 'clean' energy, the Federal Government needs to develop the 'Clean Energy Future' framework aimed at increasing deployment and innovation of renewable energy in the country.

In this study, it is established that renewable energy and energy efficiency (Demand Side Energy Management) are two components that should go together to achieve sustainable development in Nigeria. The need to conserve the present energy generated in the country using energy efficiency products and practices is essential for sustainable development.

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